CHAPTER 5
ELECTRICITY, MAGNETISM, & ELECTROMAGNETISM

X-ray Imaging System
- *Primary function:* to convert electric energy into electromagnetic energy

ELECTROSTATICS

Electrostatics
- The study of stationary electric charges

Matter has mass & energy equivalence. Matter also may have electric charge!

Electric Charge
- Positive or negative
- It has potential energy
- *Smallest Units:* electron & proton
- *Fundamental Unit (SI):* coulomb (C)
- *1 C:* 6×10^{18} electron charges

Electrified
- The object that has too few or too many electrons

Electrification
- The process of adding or removing electrons from an object
- It is created by *contact*, *friction* or *by induction*

Electric Ground
- The object that behaves as a reservoir for stray electric charges

Electrostatic Laws
- Unlike charges attract
- Like charge repel
- Electric field radiate out from positive charge
- Electric field radiate toward a negative charge
- Uncharged particles do not have electric field

Electric Field
- The lines of force exerted on charged ions in the tissues by the electrodes
- It causes charged particles to move from one pole to another
- *Positive charge:* points outward
- *Negative charge:* points toward

Electrostatic Force
- The force of attraction between unlike charges or repulsion between like charges
- Directly proportional to the product of the charges
- Inversely proportional to the square of the distance between them

Coulomb's Law
- The electrostatic force is directly proportional to the product of the electrostatic charges & inversely proportional to the square of the distance between them
- *Formula:* $F = k(Q_aQ_b/d^2)$

Electric charge distribution is uniform throughout or on the surface!

Electric charge of a conductor is concentrated along the sharpest curvature of the surface!

Electric Potential
- *SI Unit:* volt (V)
- *1 V:* 1 J/C or 1 potential energy/unit charge

ELECTRODYNAMICS

Electrodynamics
- The study of electric charges in motion

Electrical Engineer
- Work with electric current

Physicist
- Concerned with electron flow

Four States of Matter
- Conductor, Insulator, Semiconductor, Superconductor

CHAPTER 5
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Conductor
- Any substance through which electrons flow easily
- *Characteristics:*
  - Variable resistance
  - Obeys Ohm's law
  - Requires voltage
- *Examples:* copper (Z=29), aluminum (Z=13) & water

Insulator
- Any material that does not allow electron flow
- *Characteristics:*
  - Does not permit electron flow
  - Extremely high resistance
  - Necessary with high voltage
- *Examples:* glass, rubber & clay

Semiconductor
- A material that some conditions behaves as an insulator & as a conductor
- *Characteristics:*
  - Can be conductive
  - Can be resistive
  - Basis for computers
- *Examples:* silicon (Si-14) & germanium (Ge-32)

Superconductor
- Any material that allows electrons to flow without resistance
- *Characteristics:*
  - No resistance to electron flow
  - No electric potential required
  - Must be very cold
- *Examples:* niobium (Nb-41) & titanium (Ti-22)

William Shockley (1946)
- He demonstrated semiconduction

Superconductivity (1911)
- The property of some matter to exhibit no resistance below a critical temperature

Electric Circuits
- The path of electron flow from the generating source through the various components & back again

Increasing electric resistance results in a reduced electric current!

Electric Current/Electricity
- The flow of electrons through a conductor
- *Direction:* always opposite the electron flow
- It is measured in *Amperes (A)*
- *1 A:* 1 C/s or 1 electric charge/second

Electric Potential
- It is measured in *volts (V)*
- *1 V:* 1 J/C or 1 potential energy/unit charge

Electric Resistance
- It is measured in *ohms (Ω)*

Ohm's Law
- The voltage across the total circuit or any portion of the circuit is equal to the current times the resistance
- *Formulas:* V = IR; R = V/I; I = V/R

Two Basic Types of Electric Circuits
- Series & Parallel Circuits

Series Circuit
- All circuit elements are connected in a line along the same conductor

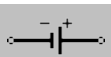
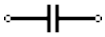
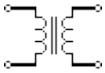
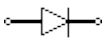
Rules for Series Circuit
- $R_t = R_1 + R_2 + R_3$
- $I_t = I_1 = I_2 = I_3$
- $V_t = V_1 + V_2 + V_3$

Parallel Circuit
- Elements are connected at their ends rather than lying in a line along a conductor

Rules for Parallel Circuit

- $I_t = I_1 + I_2 + I_3$
- $V_t = V_1 = V_2 = V_3$
- $1/R_t = 1/R_1 + 1/R_2 + 1/R_3$

SYMBOLS & FUNCTION OF ELECTRIC CIRCUIT ELEMENTS

Circuit Elements	Symbol	Function
Resistor		Inhibits flow of electron
Battery		Provides electric potential
Capacitor		Momentarily stores electric charge
Ammeter		Measures electric voltage
Voltmeter		Measures electric potential
Switch		Turns circuit on & off by providing infinite resistance
Transformer		Increases & decreases voltage by fixed amount (AC only)
Rheostat		Variable resistor
Diode		Allows electron to flow only in one direction

Direct Current

- Electrons that flow in only one direction

Alternating Current (AC)

- Electrons that flow alternately in opposite direction
- 60-Hz current

Waveform

- The graphic representation of a wave
- *x-axis:* time
- *y-axis:* amplitude of electric current
- *AC:* sinusoidal
- *DC:* straight line

Electric Power

- It is measured in *watts (W)*
- *1 W:* 1 A (current) x 1 V (voltage)
- *Formulas:* $P = IV = I^2R$

MAGNETISM

Magnetite

- Oxide of iron (Fe_3O_4)
- Lodestone or leading stone

Magnetism

- The fundamental property of some forms of matter
- It has no smallest unit

Any charged particle in motion creates a magnetic field!

Electron Spin

- A property created when electrons behave as if they rotate on its axis
- It is neutralized in electron pairs
- It creates a magnetic field

Magnetic Moment

- A nuclear magnetic dipole created when magnetic field is created by spinning electric charge
- The basis of MRI

The lines of a magnetic field are always closed loop!

Dipolar/Bipolar

- A magnet that has two poles
- *Poles:* north & south pole

Magnetic Dipole

- The small magnet created by the electron orbit

Magnetic Domain

- An accumulation of many atomic magnets with their dipoles aligned

- *In Ferromagnetic Material*: randomly oriented

Magnetic Permeability
- The ability of a material to attract the lines of magnetic field intensity

Magnets are classified according to the origin of the magnetic property!

Three Principal Types of Magnets
- Naturally occurring magnets
- Artificially produced permanent magnets:
- Electromagnets

Natural Magnet
- A magnet that gets its magnetism from the Earth

Permanent Magnet
- A magnet whose magnetism is induced artificially
- A bar or horseshoe-shaped magnet
- *Example:* compass

Electromagnet
- A coil or wire wrapped around an iron core that intensifies the magnetic field

All matters can be classified to the manner in which it interacts with the external magnetic field!

Four Magnetic States of Matter
- Nonmagnetic, Diamagnetic, Paramagnetic, & Ferromagnetic

Nonmagnetic
- Unaffected by magnetic field
- *Example:* wood & glass

Diamagnetic
- Weakly repelled from both poles of a magnetic field
- *Example:* copper, water & plastic

Paramagnetic
- Weakly attracted to both poles of a magnetic field
- *Example:* Gadolinium (Gd-64): contrast agent in MRI

Ferromagnetic
- It can be strongly magnetized
- *Example:* alnico (Al-12, Ni-28, Co-27) & iron (Fe-26)

Magnetic Susceptibility
- The degree to which a material can be magnetized

Wood
- Low magnetic susceptibility

Iron
- High magnetic susceptibility

Hysteresis
- A condition wherein some materials that are very susceptible are also reluctant to lose their magnetism

Pole
- The magnetically charged end of a material
- North & south poles

Magnetic Laws
- Like magnetic poles repel
- Unlike magnetic poles attract
- Imaginary lines of magnetic field leave the north pole
- Imaginary lines of magnetic field enter the south pole

Magnetic Induction
- The process of making ferromagnetic material magnetic

Magnetic Lines of Induction
- The imaginary magnetic field lines

Soft Iron
- An excellent temporary magnet

Ferromagnetic objects can be made into magnets by induction!

Magnetic Force
- The force of attraction between unlike poles or repulsion between like poles
- Directly proportional to the product of the magnetic pole strengths
- Inversely proportional to the square of the distance between them

Magnetic Field Strength
- *SI Unit:* tesla (T)
- *Older Unit:* gauss (G)
- *1 T:* 10,000 G

ELECTROMAGNETISM

Luigi Galvani (1700's)
- He observed that a dissected frog leg twitched when touched by two different metals

Alessandro Volta
- HE Contributed on the development of battery
- *Voltaic Pile:* precursor of modern battery
  - A copper-zinc plates like a Dagwood sandwich
- *Modern Battery:* carbon rod (+) & zinc cylindrical can (-)

Source of Electromotive Force
- Any device that converts some form of energy directly into electric energy

Ferromagnetic objects can be made into magnets by induction!

Hans Oersted (1820)
- He demonstrated that electricity can be used to generate magnetic fields

Any charge in motion induces a magnetic field!

Right Hand Rule
- It determines the direction of the magnetic field

Solenoid
- A coil of wire

Electromagnet
- A current-carrying coil of wire wrapped around an iron core
- It intensifies the induced magnetic field
- *Advantage:* magnetic field can be adjusted or turned on & off

Electromagnetic Induction
- An electric current is induced in a circuit if some part of that circuit is in a changing magnetic field
  e.g radio reception

Michael Faraday
- He observed the current in a changing magnetic field

Faraday's Law
- The first law of electromagnetic

FARADAY'S LAW

The magnitude of the induced current depends on four factors:
1. The strength of magnetic field
2. The velocity of the magnetic field as it moves pass the conductor
3. The angle of the conductor to the magnetic field
4. The number of turns in the conductor

Varying magnetic field intensity induces an electric current!

Electromagnetic Devices
- Electric motor, Electric Generator & Transformer

CHAPTER 5
ELECTRICITY, MAGNETISM, & ELECTROMAGNETISM

Electric Motor
- Electric current produces mechanical motion
- *Commutator Ring:* switches the direction of current through the loop

Electric Generator
- Mechanical motion produces electric current

Transformer
- It changes the intensity of alternating voltage & current
- It works on AC only
- *DC:* induces no current in the secondary coil

Induction Motor
- A type of motor used with x-rays tubes
- It powers the rotating anode of an x-ray tube

Transformer Law
- The change in voltage is directly proportional to the ratio of the number of turns (*windings*) in the secondary coil (N_s) to the number of turns in the primary coil (N_p)
- *Formula:* $V_s/V_p = N_s/N_p$

Step-up Transformer
- Turns ratio greater than 1
- *Primary Side:* low voltage, high current
- *Secondary Side:* high voltage, low current

Step-down Transformer
- Turns ratio less than 1
- *Primary Side:* high voltage, low current
- *Secondary Side:* low voltage, high current

Transformer Law Effect on Current
- A change in current & a change in voltage are inversely related
- Formula: $I_s/I_p = N_p/N_s = V_p/V_s$

Types of Transformer
- Closed-core, Autotransformer & Shell-type

Closed-core Transformer
- A square core of ferromagnetic materials built up of laminated layers of iron
- It helps to reduced energy losses caused by eddy current
- *Result:* greater efficiency

Eddy Current
- A current that opposes the magnetic field that induced it, creating a loss of transformer efficiency

Autotransformer
- It consists of one winding of wire & varies in voltage & current by self-induction
- It is located in the operating console that controls the kVp

Shell-type Transformer
- It confines more of the magnet field lines of the primary winding
- *Rationale:* the secondary is wrapped around it & there are essentially two closed cores
- *Advantage:* more efficient than closed-core transformer